Intellectual Property Law Department
Schlumberger-Doll Research
Old Quarry Road
Ridgefield, CT 06877-4108
Phone: (203) 431-5506
Fax: (203) 431-5640
e-mail: batzer@ridgefield.sdr.slb.com

Schlumberger

Via First Class

May 2, 2000

Exhibit A

MAY - 4 2000

David P. Gordon, Esq.
65 Woods End Road
Stamford, CT 06905

Re: New U.S. Patent Application for T. S. Ramakrishnan, R. K. M. Thambynayagam, and Peter Tilke for "m2m e-portal for OFS: A Machine-to-man Reservoir management System Through Real Time Monitoring, Strategic Alert, Diagnosis, Control and Reporting"
(Our File 60.1421) SLR-059

Dear David:

As a follow-up to our phone conversation, we would like you to prepare a draft patent application for the above-identified disclosure.

Enclosed is a copy of the Patent Memorandum and the four references listed on page 19 of this Patent Memorandum.

Please feel free to contact the inventors directly to discuss the case. The inventors' phone numbers are listed below:

T. S. Ramakrishnan (Rama), extension 5239 ← Primary Contact
R.K.M. Thambynayagam (Michael), extension 5249
P. Tilke (Peter), extension 5513

I look forward to receiving a copy of the draft application.

Sincerely,

Bill

William B. Batzer

enclosures

cc: T.S. Ramakrishnan
M. Thambynayagam
P. Tilke

SCHLUMBERGER-DOLL RESEARCH

DIVISION OF SCHLUMBERGER TECHNOLOGY CORPORATION

PATENT MEMORANDUM

Inventors: **T. S. Ramakrishnan, R. K. M. Thambynayagam and P. Tilke** Date: **4/12/00**

Title of Invention: **m2m e-portal for OFS: A machine-to-man reservoir management system through real time monitoring, strategic alert, diagnosis, control and reporting**

micro electro mechanical systems

Summary

We propose an e-well based management system comprising the following components: sensors (conventional or MEMS) for monitoring, logic for selective acquisition and storage, and communication to mail/web servers, automated diagnosis listing for possible remedial action, default control action that acts on inaction, and default document generation for reporting. The entire system will allow user-friendly customization features such as threshold parameters for alarms etc. to be altered. Our proposal is to install an addressable server for every e-well, with its own memory, CPU, logic controller, and components that act on directives from the logic controller. The logic controller mimics what an astute human observer looks in the well(s) data.

Rather than ~~an~~ inundate the asset management team with voluminous data that the human observers will have to sieve through, we propose a system that constantly analyzes the data. Essential information will be sent on a periodic basis to a host web-server. By default, a compressed form of the data will be routinely available for human observation through the web. On demand, uncompressed data will also be accessible. Rather than incorporating a simple display of data, we propose building data analysis logic within a local CPU (at the wellsite or close to it). The logic would be similar to what an intelligent human observer looks for in the acquired data using a variety of interpretation software. Because of the automation, when mission critical acquistion of data occur, a near instantaneous signal may be sent to the asset management team, prompting for preventive or corrective measure. If human inaction persists, default safety measures may be implemented.

We allow for the data analysis function to be customized and expanded. Because of the local CPU limitations, we do not recommend full scale reservoir simulation type analysis, although we do not rule out this possibility in the future.

In addition to these features, we also propose using ~~using~~ a buffered memory system. This would permit retrieving finely sampled data only when necessary. The sparsely sampled data may be stored during the operation of the field. Sufficiently old, but finely sampled data may be

Witnessed, read and understood by:		
Sarah Ryan	4/13/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/13/00	SDR
SIGNATURE	DATE	LOCATION

INVENTORS:		
[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

overwritten. The entire scheme is expected to save considerable human effort requried to monitor and manage an oil-field.

Background

The aim to access sensor readings remotely via the Internet dates back to the 1970s (Putnam, 1999). Despite the explosive growth in this area, application to the oil industry has been virtually nonexistent. Applications such as WELL WATCHER or PUMP WATCHER are typical. These are essentially passive observation systems that deliver data to a remote host, not necessarily a web server. Serious analysis of the data requires periodic human review through standard interpretation methods. At this stage, the available products are basically remote sensing and transmission units, with primitive data check algorithms.

Our approach differs by providing Internet access to each wellsite. Direct viewing of the data from any location is available by providing each installation with TCP/IP address and a web-server installed. For reasons elaborated by Putnam (1999), it is ill-advised to serve web pages from this server because of the limited computing power. Therefore they will be data servers and will be able to deliver data and information on an authenticated request. We however will allow for substantial customization for analysis of the data and information transmission. Novel interpretation methods of the acquired data are also given. To the extent possible, we allow for a one-to-one mapping between the e-well web server and the SCADA (Supervisory Control And Data Acquisition) system. Thus, if a SCADA system manages an entire platform, then only one web server is needed for the unit.

The internet-based systems have yet to realize their full potential, even with the technology available today. With permanent sensors, secured web-access and data tranmission, remote acquisition of data, selective analysis, and control action, internet based management systems are poised for tremendous growth. In the oil industry in particular, where the areal coverage of a field may be several hundred km^2, online monitoring and control strategy will result in saving considerable human time and physical effort. Furthermore, analysis of data from multiple wells is best carried out by pooling together all of the information in a centralized system. A collection of e-wells communicating to a web-server acts as multiple data servers connected to a common host. Thus, one may conceive of two-levels of data gathering and analysis. One is on an individual well basis that may or may not consist of individual production zones. The second is a field-level decision. The former is handled reasonably well with a dedicated processor system at the well with some level of local decision-making, whereas the latter by the very nature of it requires collective analysis, meaning a centralized computing environment (CCE) for field-level decisions. As stated before, if a common system manages the entire platform then it may be possible to integrate both the individual and the multiple well decision making within a single computing unit.

Witnessed, read and understood by:

[signature]	4/13/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/13/00	SDR
SIGNATURE	DATE	LOCATION

INVENTORS:

[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

In our preferred approach, we would implement a variety of permanent sensors as is necessary to monitor the well reasonably. Examples of these include but are not limited to temperature, pressure (within the well and at the sandface), electrode voltages for resistivity analysis etc. With multiple zones, instrumentation may be installed for each one. The installation of such sensors is an art that has been well documented before.

In addition to sensors in production/injection wells, we also recommend installation of low-cost *satellite* wells purely for observation, but instrumented just as the active wells. Here, well monitoring can take on an added level of automation, and through examples we show how automated interference testing may be carried out for diagonostics.

To summarize, our invention differs in concept from previous inventions by having a production system of e-wells. Each well will have a dedicated microprocessor, capable of sending data across Internet on a secure basis. Thus, each well becomes a data server. But, in addition, it will be an intelligent data analyzer, with a certain interpretation competence built into it for selective warning and action and immediate messaging. The processor will also manage intelligent data storage.

The entire concept therefore frees human observers from having to sort through large volumes of data streaming through their consoles, when bulk of the data is expected to be "routine." Nevertheless, in the past, this has tied down valuable human time. In our invention, by building an analysis engine and secured messaging across the Internet, human time is spent only when it is deemed to be warranted. Thus, we distinguish between the value of generating reams of data, and pouring over it, from supplying crucial pieces of information automatically when it matters. This underlying concept is "delivery of data that matter."

Description of an e-well

The components of an e-well are illustrated in Fig. 1. This include primarily the sensors, CPU, the sytem bus, addressable server, data storage (zero compression, decimated, strongly decimated), data analysis module, alarm/acknowledge module, controller. Each one of these components is elaborated below.

CPU

As with any computer system, the CPU is the central processor that controls all of the local well monitoring, data storage and the running of local applications. As an application server, it serves a remote web server with the necessary data, on a prespecified periodic basis. It also facilitates storage of data at various levels of compression, and the management of the buffered memory system. The application server running on the CPU manages the data analysis function, based on which it will execute the warning/alarm modules for immediate messaging to the predetermined

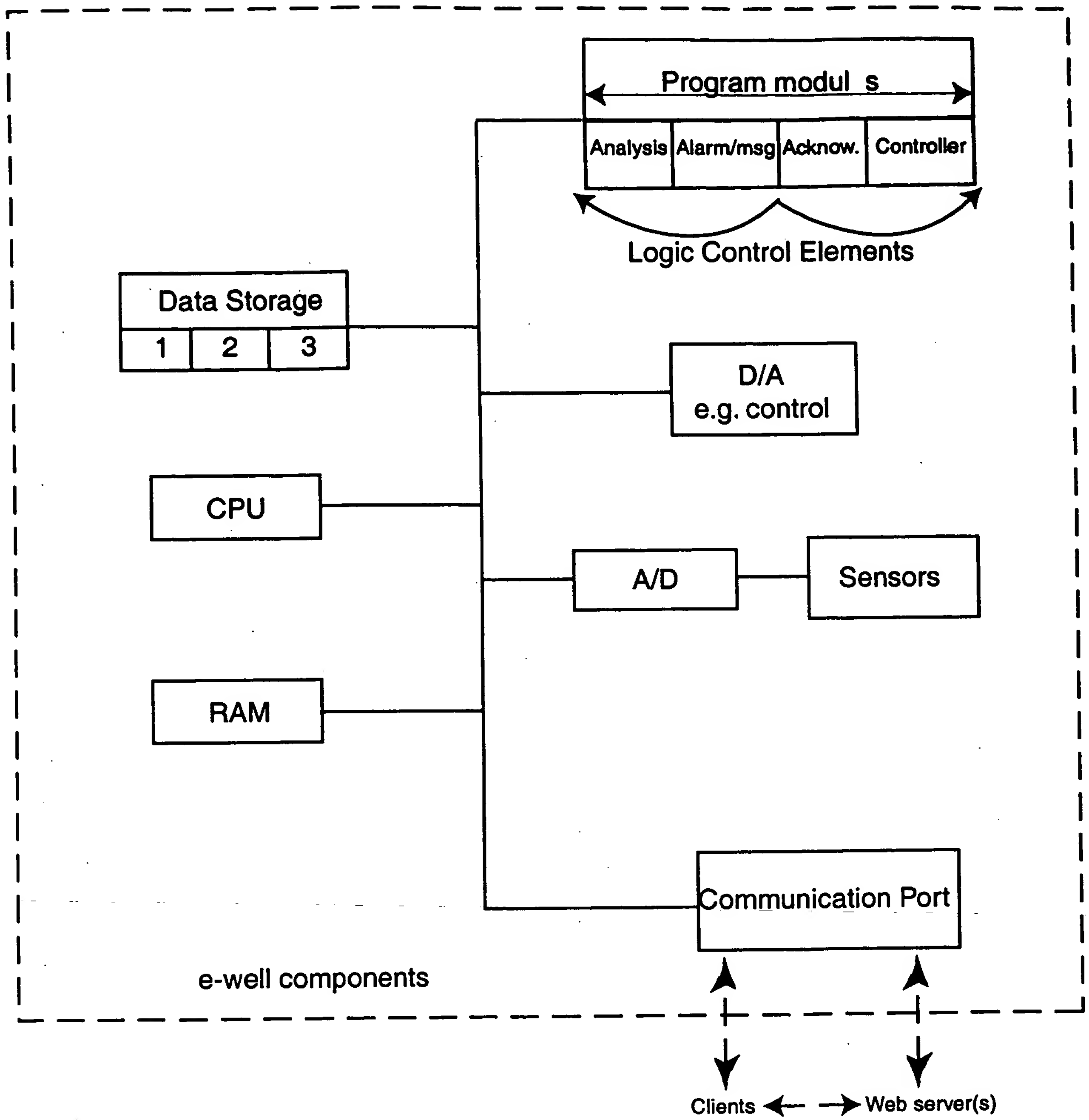

Figure 1: The components of an e-well

Witnessed, read and understood by:

4/10/2000		SDR
SIGNATURE	DATE	LOCATION
	4/13/00	SDR
SIGNATURE	DATE	LOCATION

INVENTORS:

	4/12/00	SDR
SIGNATURE	DATE	LOCATION
	4/12/00	SDR
SIGNATURE	DATE	LOCATION
	4/12/00	SDR
SIGNATURE	DATE	LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

list of hosts. The warning system activates the acknowledge module that requires action from the designated hosts according to priority levels. Depending on the warning severity, CPU will also manage the action based on lack of acknowledgment.

Sensors

The permanent sensing concept was introduced to the OFS industry a few years ago (Babour et al., 1995). Various types of sensors have been advocated, the most common among these being pressure, temperature, array of electrodes, acoustic sensors, etc. The sensors themselves may be classical as has been conventionally deployed, or based on optical fibers, or the MEMS variety. Also, the sensors may be embedded into the formation or may simply be positioned in the wellbore itself. Naturally, it is advantageous to have different data types and at different locations along and into the wellbore. The purpose of this memo is not to invent new sensor types or deployment methods, but to be able to make *the needed communication of the data nearly instantaneously*, and *take effective decisions following the measurements.*

For the purpose of further discussion we will assume that there are M classes of data points at N locations in each well and that there are K wells. M and N may be different in each well, and so for general notational purposes these are the maximal values among all the wells of interest.

We will use the first subscript of measurement P to denote the class (meaning formation pressure, wellbore pressure, temperature, voltage in a given mode, etc.), the second subscript to denote location in a well, and the superscript in parenthesis is the well. When a particular measurement is not available, we may denote it appropriately. Thus, $P_{34}^{(2)}(8)$ will mean data-point 8 of class 3 measurement (say wellbore temperature), in location 4 of well 2.

Data storage

Data may be stored in a variety of means known in the computer hardware community. For quick access to data, RAM storage is recommended. Alternatively, it may be stored in flash memory or low-power microdirves. A continuous writeup of this data into a hard disk/magneto-optical storage is expected. We will assume that sectors or different devices are available to store data at different levels of decimation/preprocessing.

Let us assume that the data are acquired on an interval $\delta_{t_{ij}}^{(k,l)}$, corresponding to $P_{ij}^{(k)}(l)$, where l is the point number for that data set. For simplicity let us assume that all of the δ are same. For every well k, each measurement $\mathbf{P}^{(k)}$ is an array of dimension $M \times N$. Each well has its own storage system at several levels of historical archiving capability stored either in different devices or sectors of the same device according to their archival tag. The archival tag simply refers to the time-extent to which data will be stored before a rewrite begins. Thus, for long term storage, only

Witnessed, read and understood by:		
Sarah Ryan	4/13/00	SDR
SIGNATURE	DATE	LOCATION
[illegible]	4/13/00	SDR
SIGNATURE	DATE	LOCATION

INVENTORS:		
[illegible]	4/12/00	SDR
SIGNATURE	DATE	LOCATION
[illegible]	4/12/00	SDR
SIGNATURE	DATE	LOCATION
[illegible]	4/12/00	SDR
SIGNATURE	DATE	LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

compressed data is expected to be kept. As a first proposal we recommend three levels of storage, each higher level having increased levels of compression/decimation of data.

If we assume that 4 bytes are required for each measurement, a well will need $4MN$ bytes for storage of each time point. With a sample every minute, this amounts to $MN \times 172K$ of memory for storing a month of data. Without any great difficulty, the raw data may be stored easily in local memory. This is a zeroth level memory sotrage system, which is indicated by adding a second superscript. The zero level data may be periodically archived through regular enquiry from the central web-server. Because the zeroth level memory is in a buffer, data rewrite of the buffer has to ensure that the archive OK marker has to be satisfied; otherwise an *urgent* warning is sent across. This has to lead the actual rewrite so that effective action may be taken. In the absence of a response, serious repercussions are avoided by having a first level storage, which will have the decimated or compressed data. The first level storage may have a year's (as an example) worth of storage, before a rewrite may occur. Again, to go to the second level of compressed storage, we do similar checks as in the zero level rewrite. We may expect that the second level storage has an even higher level of data compression to permit a storage essentially through the life of the well. Given the rapid drop in memory units, we anticipate that in the future, one or both levels of compression may be altogether avoided.

For notational purposes, we add a second superscript to denote the level of compression.

Data compression

A variety of data compression methods may be deployed. Some of the methods such as linear predictive coding (LPC) are reversible, and rely on data being close to linear prediction (Press et al., 1992). The nonreversible algorithms are least-square splines or smoothing filters such as Savitzky-Golay (Press et al., 1992) or a wavelet basis (Press et al., 1992). Our preferred choice is rather simple, consisting of choosing those points which show significant change and at the same time are not within the tolerance range of linear data fitting(Ramakrishnan and Kuchuk, 1994). In this scheme the data are stored in terms of straight lines between the preserved data points. Thus, for compression at the first level

$$P_{ij}^{(k,1)}(l) = b_{ij}^{(k,1)}(l) + m_{ij}^{(k,1)}(l)t, \quad \forall t_{ij}^{(k,1)}(l) \le t \le t_{ij}^{(k,1)}(l)\,. \tag{1}$$

Here the notation b stands for intercept, m is the slope and $t_{ij}^{(k,1)}(l)$ are the preserved nodes after decimation. For storage purposes we may not retain values for the slopes and intercepts, but may compute it as and when necessary from $P_{ij}^{(k,1)}(l)$. A level 2 scenario for such a scheme will simply set a higher threshold for data decimation.

Access to the data compression section may be periodic, triggered on a regular basis. Alternatively, it may be on the fly. The advantage of the preferred method of compression is that it is

Witnessed, read and understood by:			INVENTORS:		
[signature]	4/13/00	SDR.	[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION	SIGNATURE	DATE	LOCATION
[signature]	4/13/00	SDR	[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION	SIGNATURE	DATE	LOCATION
			[signature]	4/12/00	SDR
			SIGNATURE	DATE	LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

simple and can handle new data one set at a time. For example, if a new point is obtained and it is decided that the slope has not changed significantly, the new point will overwrite the previous one.

Data analysis module

The primary function of the data analysis module is to look for anamolies and trends. The trends and correlation functions are output on a routine basis on demand. The processed data may also reside on the central web server. While these may be considered as "regular" processing of data, the analysis module serves a major function, which is to provide instantaneous alarms to the warning module to communicate the information to a predesignated set of IP addresses for notification.

The analysis module may be customized and we include examples of these below. Each of the bulleted items is applicable for all classes of data points, in every well and location within the well. The customization function is important—experience gathered from past operations may be utilized to make the alarm system robust.

boundcheck Do any of the variables exceed any of the bounds specified? If so, send a listing to the warning module. Send also a flag to the web-server to display a notification banner. The variables include pressure, temperature, watercut, flowrates etc. Examples include pressure dropping below the bubble point in a production well, or temperature showing a sudden anamoly, indicating abnormal production profile, or watercut increasing suddenly.

trendcheck Do the data change more than a specified band from point to point? Again, examples are pressure, temperature, watercut, flowrates etc. The trend can include the measurement value and the slopes as discussed above. Whenever a point is picked by the decimation algorithm, the criterion for choosing the point is also known. Therefore, the decimation process itself is a good trend checker. When the trend is outside of the norm, a signal to the warning module is then sent with the necessary information. The warning module takes the responsibility of initiating a warning alarm only when warranted. Thus, a pressure decline curve is automatically watched. A rapid decline in flowrate in one section may be indicative of progressive welldamage requiring a remedy job.

fncheck Do any function of the measurements fall outside of the limits. For example, one may need a warning when the combined flowrate of all the completions exceed a limit, because it exceeds surface capacity. Or when the pressure in one layer differs from one another one by more than a certain amount indicating problems of cross flow. A similar situation arises when water-cut from one production stream is quite different from another, and it may become uneconomical to mix the two streams. Clearly these are all compactly represented as a function-check module. We will allow for a definition set of function arrays, and customizable error check for

Witnessed, read and understood by:

SIGNATURE	DATE	LOCATION
[signature]	4/13/00	SDR
[signature]	4/13/00	SDR

INVENTORS:

SIGNATURE	DATE	LOCATION
[signature]	4/12/00	SDR
[signature]	4/12/00	SDR
[signature]	4/12/00	SDR

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

all of these function. Note that boundcheck function employs only one measurement, whereas fncheck deploys combinations of several measurements.

corrcheck Just as trendcheck expands boundcheck and looks for time-dependency, we also deploy correlation function check among the measurements. Due to random fluctuations in one well or the other, we might expect a correlation function to be roughly in a $-T$s to Ts band, where T is the characteristic correlation time for the signal propagation between the two wells for the measurement in question. Based on our computatations we find this to be not robust. This is illustrated through detailed computations in Appendix A.

Periodic pulsing of the production/injection well causes a change in the nearby observation point. We have demonstrated correlation methods (see Appendix A) to show that a peak in the correlation function is a direct interpretation of well to well properties. Any shift in the peak from periodic automatic pulsing is an indicator of reservoir alteration and therefore warrants a signal. The corrcheck can also be applied across layers.

A continuous monitoring of reservoir permeability and productivity is best done with an observation well and an active well. When two active wells are involoved, correlation based processing methods are possible provided one is careful about the pulsing process and windowed computation.

The correlation process suggested in this memo is also an efficient reservoir characterization tool, whereby both reservoir connectivity and the intervening properties are quickly estimated.

covarcheck Additional computations for the covariance of the measurements and their time evolution could also be constructed.

The computationally intensive algorithms often require multiple well data. Also, because of the need to limit local processor loading, it may be preferable that some of the correlation and covariance calculations be done at the host web-server level and generate messages from there. Broadly speaking, field-level warnings may be generated by the web-server, and individual well-level warnings are issued from the local data server.

Warning module

The warning module is responsible for receiving signals generated by anamolies, along with the needed messages that indicate the cause. Depending upon the warning severity, an immediate broadcasting via email, mobile phone or pager may be sent. The messaging conditionals are entirely up to the asset team. The definition of who receives what messages, and the authority to take remote corrective action can be defined in terms of users and groups, just as in a computer network. For

additional security the remedial action may be governed through standard techniques available with smartcards.

Acknowledge module

A warning message may request a two-level acknowledgment from the receiver. On receipt of a message, the receipients are expected to respond. This is the first level acknowledge. The acknowledge module keeps track of this. If no acknowledge is received, higher priority messages are generated. Depending on the level of the warning message and the category it belongs to (this will be customizable), action may be automatically taken. As an example consider water-cut in an interval exceeding a particular value. If no acknowledgement is received for two-reminders at the first level, it is perfectly appropriate for automated choke action to throttle the flow from the offending layer. Action following inaction is executed via the auto-action control-module.

A second-level acknowledgement is requested for action following first-level receipt from the user(s). In such a case, auto-action module is not executed as above. Rather, a request is made to follow with user action within a specific time-period. In the absence of specific human intervention, the auto-action module is executed. Note that for all of the actions taken by anyone of the users, immediate messaging to all parties in the defined list will be sent. According to the defined user list, any person with a higher priority number can override the previous user's action after authorizing the override.

Control module

The auto-action control-module takes over upon no action from the defined user list. This is defined for each warning category and the severity. As stated before, throttling a section down upon unacceptable water-cut, or preventing pressure from dropping below a set-value by throttling, or increasing injection rate for pressure support etc. are normal actions that any human interventionist would have executed. With an e-well, these actions are carried out when such an execution fails to materialize.

Appendix A—The correlation example

Most of the concepts in boundcheck, trendcheck etc. may be programmed based on the information stated above. In this appendix, we will clarify the issue of correlation through the physics of pressure diffusion and some illustrative examples.

The problem posed here consists of an arbitrary number of vertical line-source wells distributed in a laterally infinite formation. Each well is allowed to produce or inject fluids. The rate schedule

consists of arbitrary step changes to rates at time points. The step changes are allowed to grow to the new rate with a specified time-constant, *i. e.* pulses with exponential increase or decline.

If the response function for pressure in well i due to flow in well j is G_{ij}, then for all practical purposes we may superpose the result to write

$$p_i = \sum_j \int_0^t G_{ij}(t-\tau)\, dq_j(\tau)\,. \tag{2}$$

The response function G_{ij} is

$$G_{ij}(t) = \frac{\mu}{4\pi kh}\,\mathrm{E}_1\left(\frac{\phi\mu c r_{ij}^2}{4kt}\right), \tag{3}$$

where E_1 is the exponential integral, ϕ is the porosity, μ is the shear viscosity, c is the compressibility, k is the permeability, t is the time, and r_{ij} is the distance from well i to j. For computational purposes we allow random fluctuations in flow rates in addition to the imposed steps. The calculations shown below are carried out with a 2% noise in rates.

In the example, we have three wells. Well 1 and 3 are active wells, 40 m apart, and well 2 is a passive or observation well. The permeability of the formation is 100 md. Well 1 and 2 are 40 m apart, whereas well 2 and 3 are 80 m apart. The viscosity is 1 cp, and compressibility $4 \times 10^{-9}\,\mathrm{m^2\,N^{-1}}$. All the trial calculations included an initial step on which were superimposed random fluctutations. When no additional pulses were included we found that it was difficult to discern any influence of the random fluctuations. *Physically, if the transient time for diffusion is much larger than the time scale of the fluctuations, then the time signature of the random fluctuations is essentially lost at the remote points.* Therefore any inference that takes advantage of the propagation of the random fluctuations in unlikely to be robust.

For the above-mentioned reason, we experimented with periodic finite-amplitude pulsing of the active wells. The pulsing sequence for wells 1 and 3 is shown in Figs. 2 and 3. Taking advantage of the notion that the propagation will be governed by pressure diffusion, whose characteristic time is $r^2/(4\mathcal{D})$, where $\mathcal{D} = \frac{k}{\phi\mu c}$, it is our notion that the correlation time for pulse propagation should be expected to approximate this value. *Thus, periodic pulsing and a direct correlation function plot will have a peak around the diffusion time-scale.*

Correlation may be carried out in a number of different ways. The most obvious method is to correlate the flow rate in an active well to the pressure in an observation well. From a signal-processing point of view, this is a poor implementation. Because of the finite amplitude background in both the pressure and the flowrate, the correlation function does not indicate diffusion time-scales. After several numerical experimentations our recommended procedure is as follows.

- Let the active wells produce or inject with a nearly constant rate.

Witnessed, read and understood by:

[signature]	4/13/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/13/00	SDR
SIGNATURE	DATE	LOCATION

INVENTORS:

[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

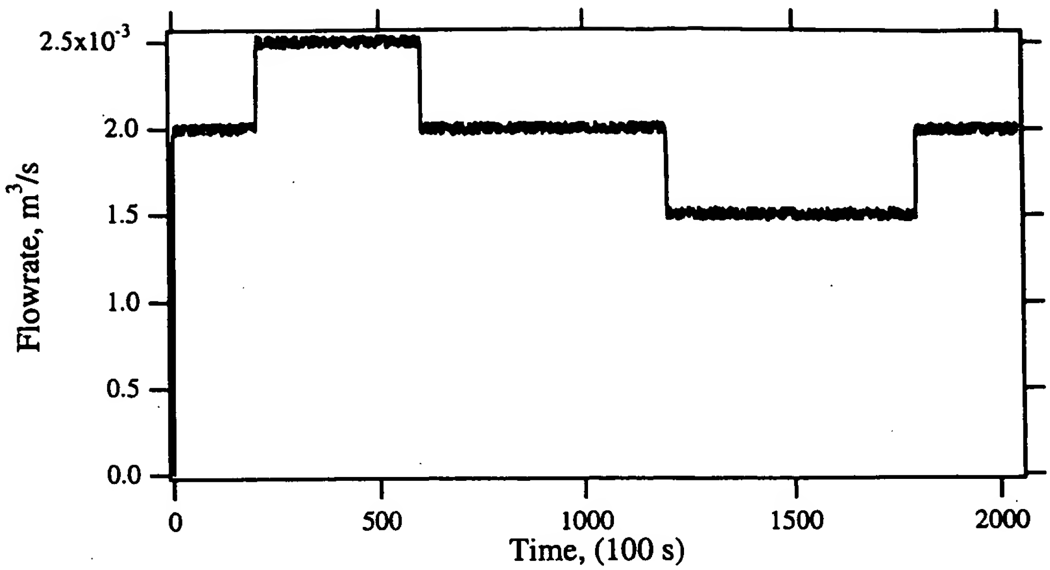

Figure 2: Flowrate pulsing in well 1.

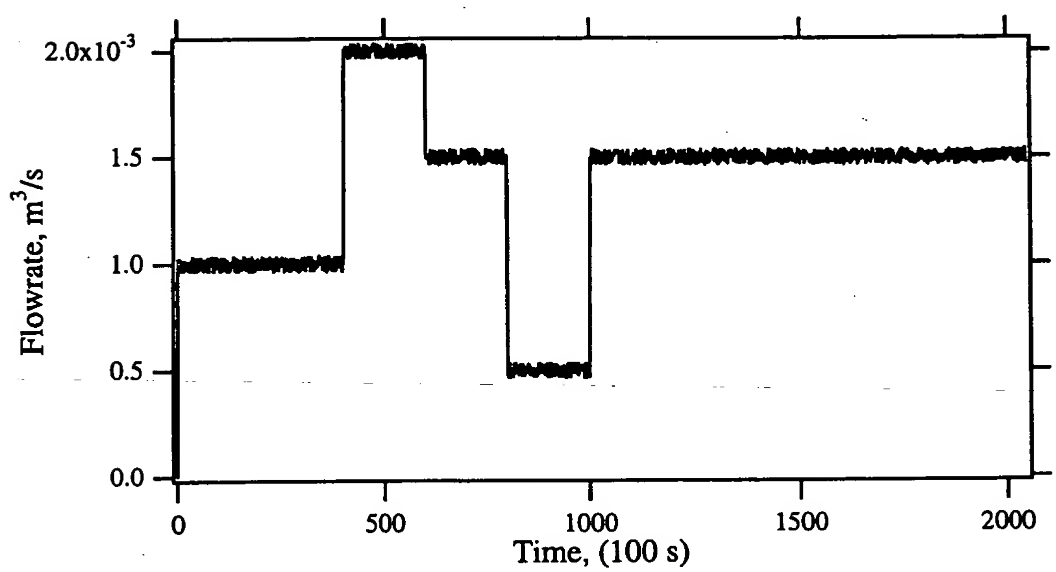

Figure 3: Flowrate pulsing in well 3.

Witnessed, read and understood by:

4/13/2000 SDR
SIGNATURE DATE LOCATION

4/13/00 SDR
SIGNATURE DATE LOCATION

INVENTORS:

4/12/00 SDR
SIGNATURE DATE LOCATION

4/12/00 SDR
SIGNATURE DATE LOCATION

4/12/00 SDR
SIGNATURE DATE LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

- A periodic flowrate pulsing of the wells will be carried out; but the active wells will not be pulsed at the same time or with the same amplitude. This ensures that the sources are not perfectly correlated. The flowrate pulsing results in pressure fluctuations in each well.
- Since the background is predominantly uniform, we differentiate both the flowrate and pressure data. (If necessary, the differentiation may be based on the decimated data, to avoid strong noise influence; we found this to be unnecessary with 2% noise). The differentiated data is composed of a nearly null background and pulses. The pressure pulses will of course be diffused.
- We may window the differentiated data and evaluate the correlation of two functions through well-known FFT methods. The cross-correlation may be done with flowrate and pressure or pressure and pressure (all of them after differentiation with respect to time). The latter has the advantage that it is less noisy, and is easily measured.
- A search is made for an easily discernible peak in the correlation function. The location of the peak automatically tells us the correlation time. The value of this is converted to mobility and displayed.

Because of the essentially signal processing nature of the above algorithm, the process is automated rather easily. *The novelty of the process is that we have converted the essential physics of pressure propagation into a signal processing issue.*

We now illustrate the results of the above process for the example considered. For the flowrate pulsing shown in Figs. 2 and 3 we show the pressure responses in Figs. 4, and 6. Note the sluggishness of the response in the observation well. The differentiated pressure signal in well 2 is obviously noisy and is shown in Fig. ??. Nevertheless, the intentional pulsing dominates over the noise spikes.

The correlation function between $\frac{dq}{dt}$ in well 1 and $\frac{dp}{dt}$ in well 2 and also between the two pressures are shown in Fig. . The location of the peak in this plot is at 3600 s, a measure of the correlation time T_c. A similar correlation between differentiated pressures in given in Fig. . The peak here is located at 3200 s. An estimate of the permeability between the two wells may be obtained from

$$k = \frac{\phi \mu c r_{ij}^2}{4T_c}, \tag{4}$$

which gives 89 mD and 100 mD respectively.

When we do a similar analysis between well 2 and 3, the peak in the correlation function is no longer reflective of the formation property. The distance between these two wells is 80 m and the interaction signal is dwarfed compared to the one between wells 1 and 2. For example, consider a

Witnessed, read and understood by:

4/13/2000 SDR
SIGNATURE DATE LOCATION
4/13/00 SDR
SIGNATURE DATE LOCATION

INVENTORS:

4/12/00 SDR
SIGNATURE DATE LOCATION
4/12/00 SDR
SIGNATURE DATE LOCATION
4/12/00 SDR
SIGNATURE DATE LOCATION

Use additional sheets if necessary–have each sheet witnessed.
Forward to your supervisor for immediate transmittal to SDR Patent Department.

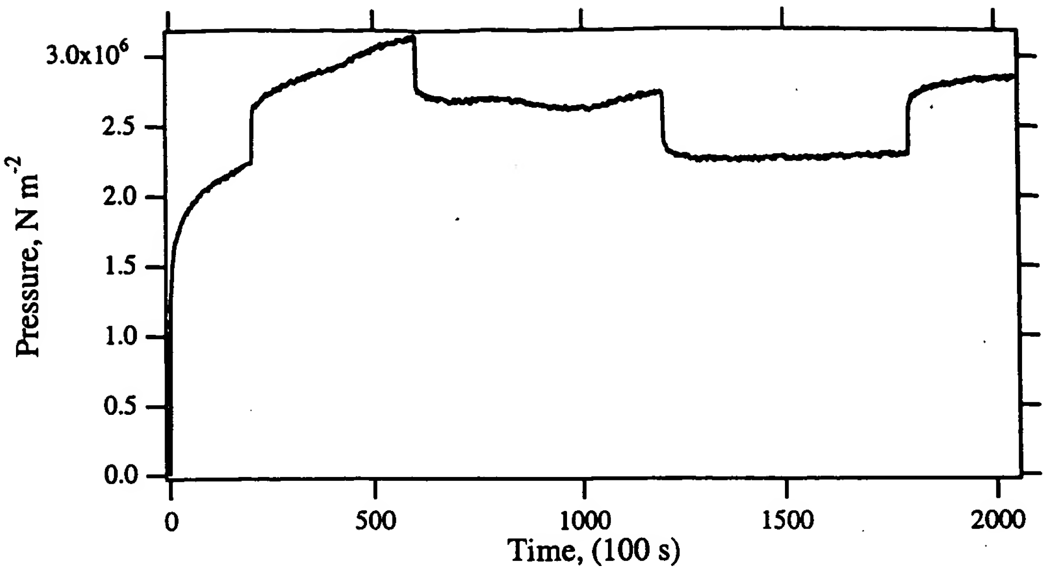

Figure 4: Pressure response in well 1.

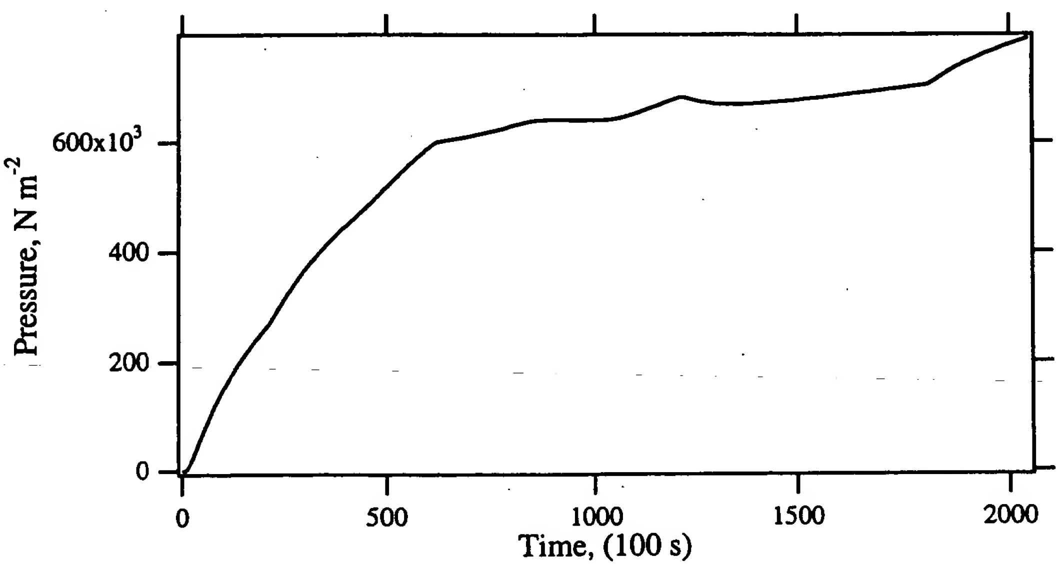

Figure 5: Pressure response in well 2.

Witnessed, read and understood by:

Sarah Ryan 4/13/00 SDR

SIGNATURE DATE LOCATION

4/13/00 SDR

SIGNATURE DATE LOCATION

INVENTORS:

4/12/00 SDR

SIGNATURE DATE LOCATION

4/12/00 SDR

SIGNATURE DATE LOCATION

4/12/00 SDR

SIGNATURE DATE LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

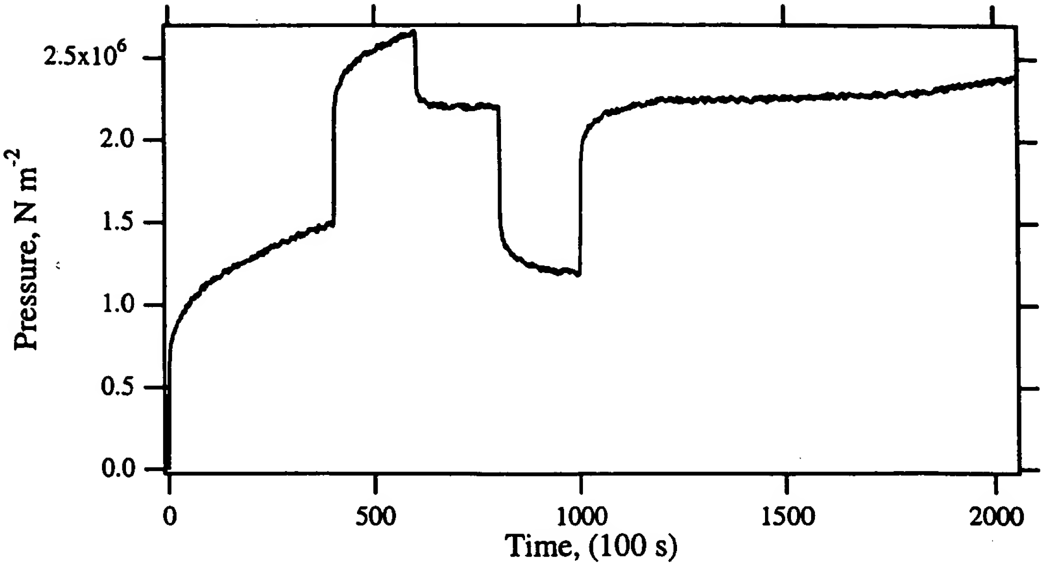

Figure 6: Pressure response in well 3.

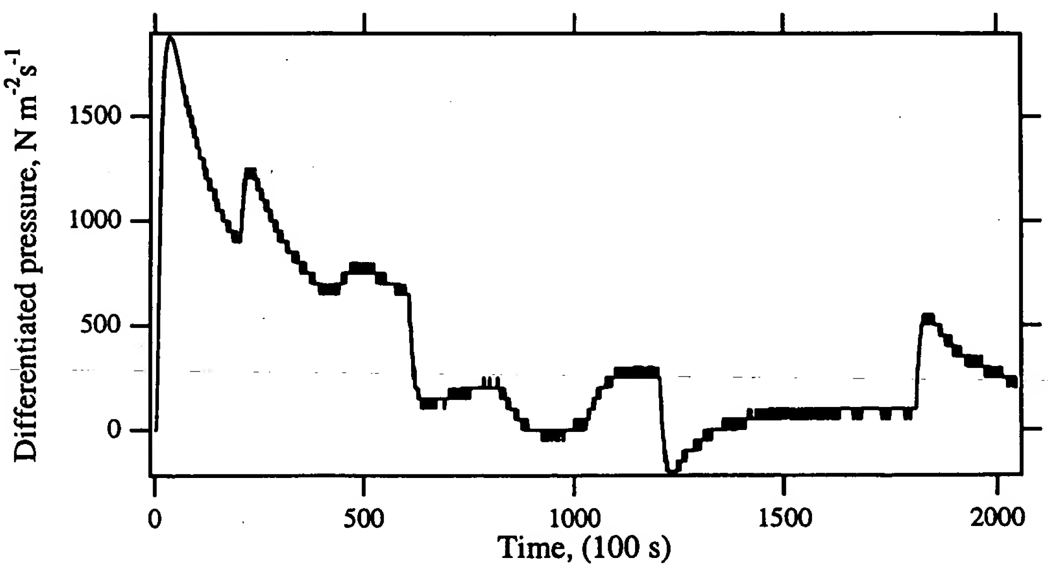

Figure 7: Differentiated pressure response of well 2.

Witnessed, read and understood by:

4/13/2000 SDR
SIGNATURE DATE LOCATION

4/13/00 SDR
SIGNATURE DATE LOCATION

INVENTORS:

4/12/00 SDR
SIGNATURE DATE LOCATION

4/12/00 SDR
SIGNATURE DATE LOCATION

4/12/00 SDR
SIGNATURE DATE LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

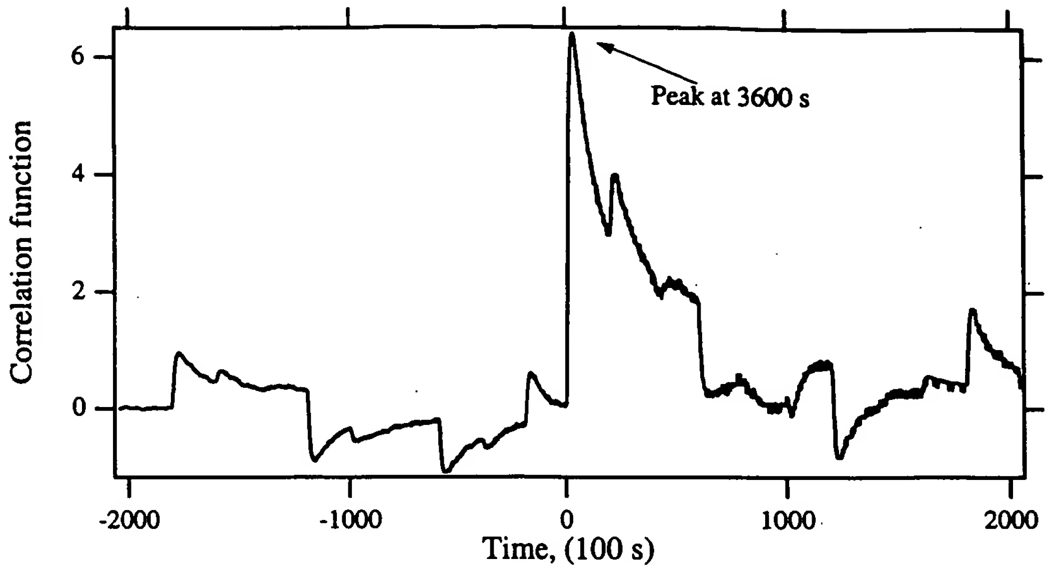

Figure 8: Correlation function of differentiated flow in well 1 and differentiated pressure in well 2.

pulse imposed by well 1 with no change in well 3. Then, both wells 2 and 3 experience a response corresponding to a distance of 40 m. These two signal changes are essentially the same in both the wells and will therefore have zero time displacement. Rather than have a correlation function peak at 12800 s $\equiv$ 80 m, a peak will appear at zero. Thus, interaction between distant wells will be badly affected by more dominant near-well signals. One could always circumvent this by looking at a targeted window correlation function calculation. For example, in this case we could choose a window around 1000 s where well 1 has no pulse. A correlation function based on this window is shown in Fig. 10. The correlation function peak now is in agreement with the diffusion time scale of 12800 s. Thus, any automated pulsing sequence and windowing should be implemented so that the observation-active well interaction is the dominant one.

Although we have demonstrated the correlation method between an active well and an observation point, we can do the same between two active wells. According to the above-discussed logic, we have to ensure that only one well is pulsed at a time. For the same window around 1000 s, we now show the correlation function between wells 1 and 3 in Fig. 11. The correlation function is noisy, with no discernible peak meaning that the local noise (if present) in a production well will dominate over response due to distant action. If the response had been ideal, a distance of 40 m suggests a peak for the correlation function at 3200 s.

Witnessed, read and understood by:

4/13/2000 SDR

SIGNATURE DATE LOCATION

4/13/00 SDR

SIGNATURE DATE LOCATION

INVENTORS:

4/12/00 SDR

SIGNATURE DATE LOCATION

4/12/00 SDR

SIGNATURE DATE LOCATION

4/12/00 SDR

SIGNATURE DATE LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

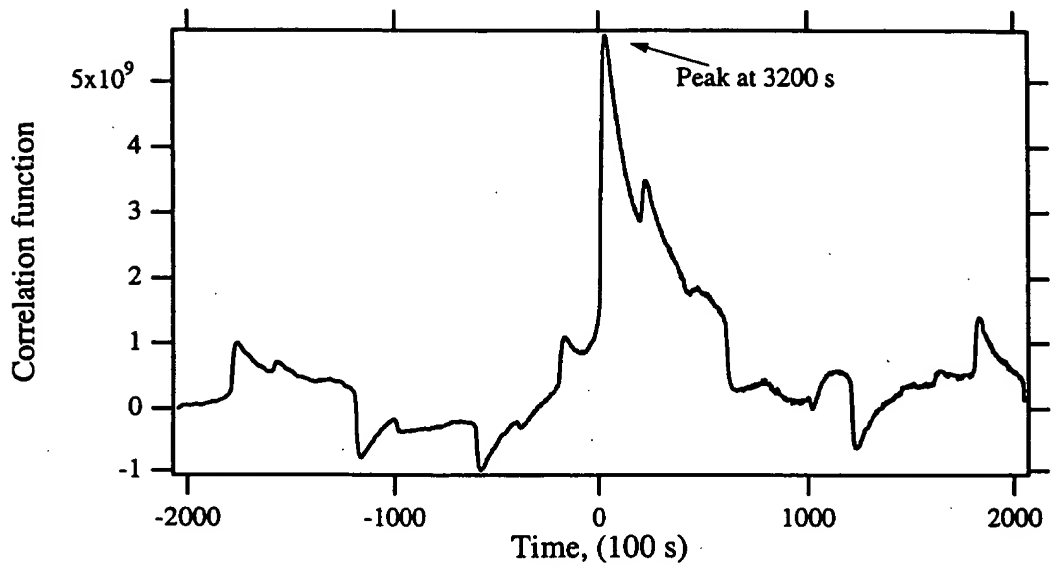

Figure 9: Correlation function of differentiated pressures in wells 1 and 2 and differentiated pressure in well 2.

Witnessed, read and understood by:

[signature]	4/13/2000	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/13/00	SDR
SIGNATURE	DATE	LOCATION

INVENTORS:

[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION
[signature]	4/12/00	SDR
SIGNATURE	DATE	LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

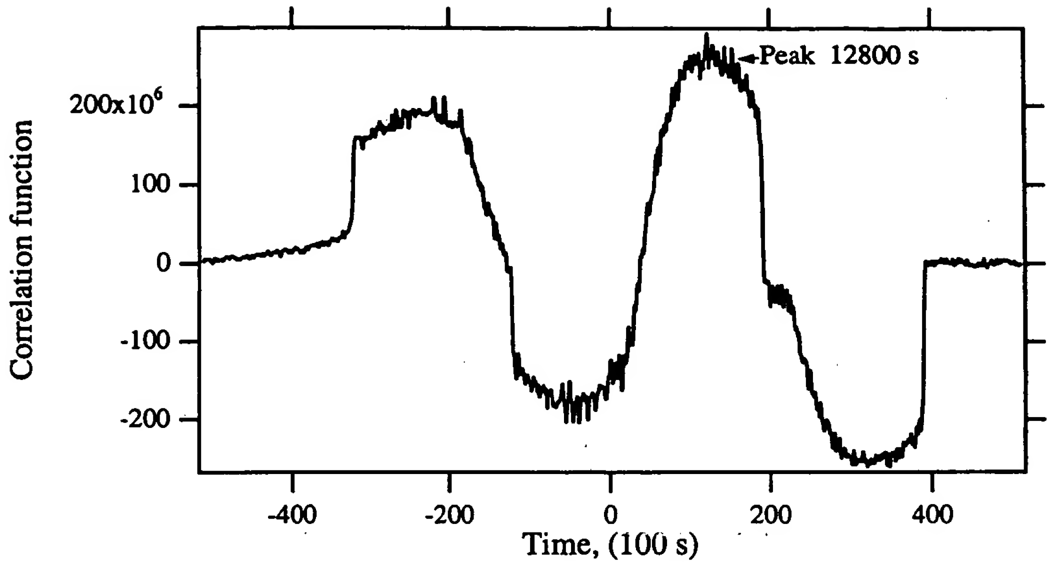

Figure 10: Correlation function of windowed differentials in pressure between wells 2 and 3, 80 m apart.

Witnessed, read and understood by:

4/13/2000		SDR
SIGNATURE	DATE	LOCATION
4/13/00		SDR
SIGNATURE	DATE	LOCATION

INVENTORS:

	4/12/00	SDR
SIGNATURE	DATE	LOCATION
	4/12/00	SDR
SIGNATURE	DATE	LOCATION
	4/12/00	SDR
SIGNATURE	DATE	LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

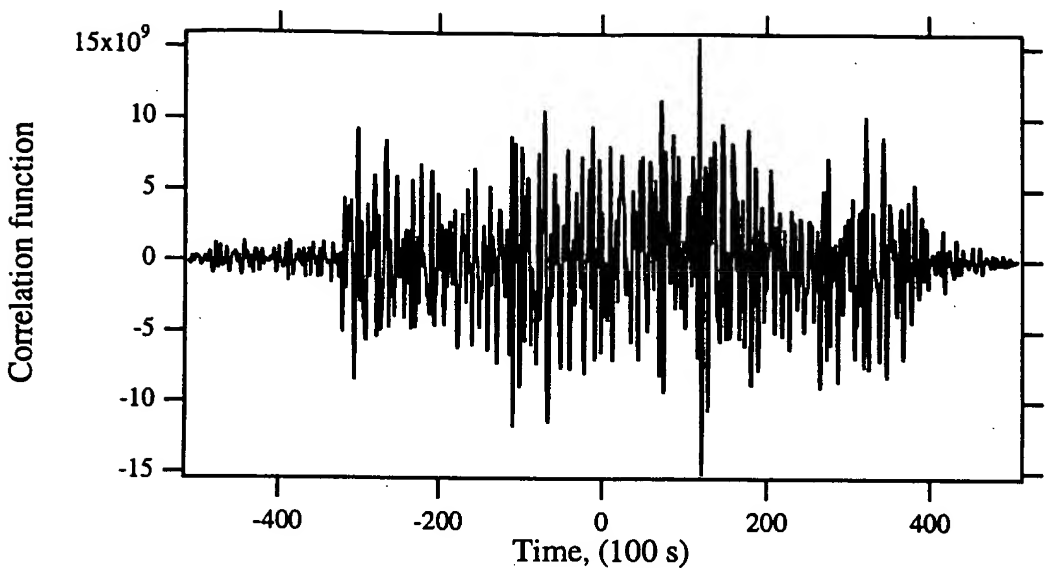

Figure 11: Correlation function of windowed differentials in pressure between active wells 1 and 3, 40 m apart; the random noise in the production well data dwarfs the interference pressure signal in this example.

Witnessed, read and understood by:

4/13/2000 SDR

SIGNATURE DATE LOCATION

4/13/00 SDR

SIGNATURE DATE LOCATION

INVENTORS:

4/12/00 SDR

SIGNATURE DATE LOCATION

4/12/00 SDR

SIGNATURE DATE LOCATION

4/12/00 SDR

SIGNATURE DATE LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.

The following conclusions may be drawn based upon all of our numerical calculations.

- Correlation functions between differentiated pressure/flowrate at the source and the pressure at the nearest (in the sense of pressure diffusion) observer are relatively roubst, and a fairly sharp peak is indicative of the properties of the intervening formation.
- The correlation gets broader as the distance to the observation well increases. Thus, the uncertainty increases.
- Evaluation of interaction between observation wells is not feasible with selective pulsing and windowing.

In this appendix, we have thus shown that straight forward signal processing methods that take into account the diffusion physics can be used in either a manual or automatic mode to generate reservoir properties between two wells or zones of interest. Such a table of generated values may be relayed periodically through our data server.

The main differentiation between conventional well testing and what we propose here is the absence of an underlying model of the reservoir. We use the very basic concept of diffusion, and then use signal processing methods to unearth the information contained within the signals.

References

K. Babour, A. K. Belani, and J. Pilla. Methods and apparatus for long term monitoring of reservoirs. U.S. Patent 5,467, 823, 1995.

W. H. Press, S. A. Teukolsky, W. T. Vertterling, and B. P. Flannery. *Numerical Recipes in Fortran.* Hemisphere publishing, Cambridge University Press, Cambridge, 1992.

F. A. Putnam. Internet-based data acquisition and control. *Sensors*, 16(11):60–63, 1999.

T. S. Ramakrishnan and F. Kuchuk. Testing and interpretation of injection wells using rate and pressure data. *SPE Formation Eval.*, 9:228–236, 1994.

Witnessed, read and understood by:

Sarah Ryan 4/13/2000 SDR

SIGNATURE DATE LOCATION

4/13/00 SDR

SIGNATURE DATE LOCATION

INVENTORS:

4/12/00 SDR

SIGNATURE DATE LOCATION

4/12/00 SDR

SIGNATURE DATE LOCATION

4/12/00 SDR

SIGNATURE DATE LOCATION

Use additional sheets if necessary–have each sheet witnessed.

Forward to your supervisor for immediate transmittal to SDR Patent Department.